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The mechanical testing facilties at the University of California, Davis have been upgraded through the purchase of a servohydraulic testing machine, a high temperature high vacuum creep machine, an ion beam milling system for TEM specimen preparation and a computer-based acquisition system. This equipment is being used to study the basic relationships between microstructure and mechanical properties in high temperature structural materials.

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FINAL REPORT

for

Grant No. AFOSR 87-0239

# High Temperature Mechanical Testing Facilties

submitted to:

AFOSR/NE
Building 410
Bolling Air Force Base, D.C. 20332-6448
Attention: Dr. Alan H. Rosenstein

submitted by:

Professors Amiya K. Mukherjee and Jeffery C. Gibeling
Division of Materials Science and Engineering
Department of Mechanical Engineering
University of California, Davis, CA 95616

September 9, 1988

## I. Introduction

This grant was awarded for the purchase of equipment to upgrade the mechanical testing facilities at the University of California, Davis. This equipment is being used in connection with investigations to explore the basic relationships between microstructure and mechanical properties in high temperature structural materials. This program of research has been and, with the equipment purchased with this award, will remain a productive area of activity.

The major items purchased under this grant include a complete servohydraulic testing system, a high temperature high vacuum creep testing system, a computer based data acquisition system and an ion milling system for TEM specimen preparation. Each of these items is described in more detail in the Section II. This equipment has been installed in our laboratory. With the exception of the high temperature creep machine, all of these systems are fully functional and are currently being used by students for ongoing research. The creep machine will be operational upon completion of the vacuum system, which we anticipate to be within one month. The use of the instrumentation acquired under this award is described in more detail in Section III.

## II. Equipment Acquired

The following items were purchased using funds obtained from this grant. As required under the terms of the grant, cost sharing of $20,000 has been provided by the University of California.

A. Servohydraulic Testing System

| Model # | Item | Cost ($) |
|---|---|---|
| MTS Systems Corp., Minneapolis, MN | | |
| 810.22 | 22,000 Pound Material Testing System . . . . | 45,000.00 |
| | Port Shutoff . . . . . | 560.00 |
| Applied Test Systems, Butler, PA. | | |
| ATS 3320 | Split Test Furnace. . . . . | * |
| Instron Corporation, Canton, MA. | | |
| 2601-001 | High Magnification Calibrator . . . . . | 2,430.00 |
| | Total . . . . . | 47,990.00 |

* The cost of the high temperature furnace is included in the total price of the vacuum creep machine, Section II.D below, because all items purchansed from ATS were included on a single purchase order.

The mechanical testing system purchased from MTS differs substantially from the description in the grant proposal. The original proposal included several individual items that were intended to be used to upgrade an existing servohydraulic load frame. However, very favorable pricing on a completely new system was obtained from MTS Systems Corporation in exchange for evaluation of some mechanical testing software. This resulted in a savings of $6,730 on the cost of the system compared to normal list price. For this reason, were we able to purchase the complete system rather than individual upgrade parts. This new system will provide significantly better performance and will better enable us to meet our research goals.

B. Data Acquisition and Control System

Hewlett Packard Company, Palo Alto, CA.

| Model # | Item | Cost ($) |
|---|---|---|
| D1322A | Vectra ES/12 Model 22 Computer | 3591.50 |
| 45951A | Vectra DOS 3.2 | 52.25 |
| 35743A | Enhanced Graphics Display | 464.75 |
| 82959S | Tilt/Swivel Base | 52.25 |
| 82300A | HP BASIC Language Coprrocessor | 712.25 |
| 82303A | RAM Expansion Kit | 272.25 |
| D1387A | Numeric Coprocessor | 247.50 |
| 45813A | 4 each 3 1/2 inch Flexible Disc Drive | 715.00 |
| 45986A | Security Lock | 27.50 |
| 10833D | 2 each HPIB Cable | 88.00 |
| 10833B | 2 each HPIB Cable | 99.00 |
| 7475A | Graphics Plotter, Option 001 Serial Interface | 1042.25 |
| 17255D | RS232 Cable | 22.00 |
| 33440A | LaserJet II Printer | 1427.25 |
| 33443A | Memory Expansion | 272.25 |
| 24542D | Parallel Printer Cable | 30.25 |
| 92286N | Font Cartridge | 137.50 |
| 92286J | Font Cartridge | 137.50 |
| 3457A | 3 each Digital Multimeter | 7830.00 |
| Opt. 908 | Rack Mount Kit for 3457A | 83.70 |
| 44492A | Multiplexer | 414.00 |
| 46060A | HP-HIL Mouse | 81.40 |
| | Total | 17,800.35 |

The data acquisition equipment listed above represents essentially the same components that were described in the grant proposal. The model numbers are slightly different due to changes in system configurations by

Hewlett Packard.

C. Specimen Preparation Equipment

GATAN INC., Pleasanton, CA

| Model # | Item | Cost ($) |
|---|---|---|
| 600-DIF | Duo Ion Mill - Diffusion pump version. . . . | 33000.00 |
| 600-2100 | 2 ea. Electronic gas flow modules. . . . . | .2920.00 |
| 600-4300 | Dual laser automatic terminator control unit | .2865.00 |
| 600-3212 | Laser head assembly ($1,460 value *) . . . . . | 0.00 |
| 600-3300 | 2 ea. Cold stage and dewar . . . . . | .3200.00 |
| 600-3500 | Liquid Nitrogen trap . . . . . | .1070.00 |
| 600-SPK | Spare parts kit. . . . . | 975.00 |
| 601-0000 | Ultrasonic disc cutter . . . . . | .3200.00 |
| 601-0500 | Microscope and x-y positioning table . . . . . | 725.00 |
| 601-0303 | 2 ea. 3.0 mm cutting tool. . . . . | 114.00 |
| 601-0309 | Extra copper washers . . . . . | .27.00 |
| 656-0000 | Dimple grinder . . . . . | .7500.00 |
| 656-0159 | Flat 15 mm grinding wheels . . . . . | 128.00 |
| 656-0106 | Spherical 15 mm grinding wheels. . . . . | 128.00 |
| 656-01-040 | 50 Extra felt polishing strips . . . . . | 103.00 |
| 623-0000 | Disc grinder . . . . . | 570.00 |
| 623-0008 | Stainless steel and glass specimen mounts. . . | .65.00 |
| 623-3000 | Specimen lapping kit . . . . . | 460.00 |
| 659-0000 | Disc punch . . . . . | 975.00 |
| | Total. . . . . | .58,025.00 |

GATAN was pleased to include one item (*) without charge.

Due to the added expense of the vacuum system for the ATS creep machine (Section II.D below), the Isomet low speed saw described in the grant proposal was not purchased.

D. High Temperature Vacuum Constant Stress Creep Machine

Applied Test Systems, Inc., Butler, PA

| Cat. # | | Item | Cost ($) |
|---|---|---|---|
| 2810 | | 2000 # Constant Stress Creep Frame | 9710.00 |
| | | Control Cabinet for Temperature and SLVC | 370.00 |
| | | Load Weight Elevator | 1410.00 |
| 4021 | | Alignment Coupling | 500.00 |
| 3320 | * | 2 ea. Single Zone 1500 C Split Furnace | 6260.00 |
| | * | 4 ea. Thermocouples (Type B, Pt-Rh) | 940.00 |
| | | 2 ea. Mounting Brackets | 500.00 |
| 2010/HT | | Programmable Controller | 3235.00 |
| | | Over-Temperature Shutdown Control | 510.00 |
| | | Extra Heating Element | 165.00 |
| 4115 | | TZM Extensometer | 2650.00 |
| 1082B | | 0.5 inch Range SLVC | 1020.00 |
| 22 | | SLVC Power Supply | 870.00 |
| 3920 | | Ceramic Retort Assembly | 8870.00 |
| | | Extra Ceramic Retort Tube | 900.00 |
| | | Inconel Retort Tube | 720.00 |
| 4043 | | Pr. TZM Pull Rods | 1100.00 |
| 4031A | | Pr. TZM Clevis Coupling | 750.00 |
| | | Modification to Frame (increase width) | 200.00 |
| | | Modification to Furnace (1600 C) | 800.00 |
| | | Modification to Furnace Controller (30 amp) | 50.00 |
| | | Less 5% University Discount | -2076.50 |
| | | Shipping | 508.08 |

Summit Level Engineering, Woodland, CA

| | | | |
|---|---|---|---|
| | | Custom vacuum system | 8488.77 |
| | | Total | 48,450.35 |

* The second furnace is for use on the MTS frame described in Section II.A.

The vacuum system originally quoted by ATS was determined to be of inadequate capacity for our planned testing. Their estimate of over $10,000 for an upgraded vacuum system would have exceeded the available grant funds. As requested in our letter of 21 August 1987 and approved by AFOSR in a letter of 8 October 1987, we had a custom system designed and fabricated at a lower price using some spare components in our lab. Unfortunately some of the existing components could not be used since they were too old to be dependable or repaired, so the actual price is higher than that estimated in our letter, but less than that quoted by ATS.

## III. Research Applications

The equipment purchased under this award has significantly improved our facilities for studying the mechanical behavior of structural materials. These enhancements have resulted in benefits to our current research activities and will enable us to expand our future programs in new directions. In particular, the availability of this equipment has enabled us to propose to AFOSR a major new program on the deformation, creep and fatigue of dispersion strengthened niobium alloys. This program would not be possible without the equipment provided under the present award. In this section, we briefly outline some of the present and anticipated applications of the new instrumentation.

The servohydraulic system is presently being used by three graduate students on a variety of research projects. This work includes an NSF sponsored program on mechanisms of inelastic deformation of metals, for which we are using the system to conduct stress rate change experiments. These tests require a high degree of control stability as well as high data acquisition resolution in order to accurately characterize the change in strain rate associated with the change in stress rate. The system is also being used in a low cycle fatigue study of dispersion strengthened aluminum alloys. This project is funded by a faculty research initiation grant from the University of California. However, the materials and properties that we are studying are of direct interest to the Air Force. Finally, this system will be used in the proposed AFOSR program on low cycle fatigue of dispersion strengthened niobium alloys. In fact, a part-time graduate student from McClellan AFB has already started some of the background work for this program using the servohydraulic testing system. If funding for this project is received as anticipated, this system will be used extensively for this work, and it will be equipped with the high temperature furnace for tests above ambient.

The data acquisition system is being used primarily in conjunction with the servohydraulic testing system. We have developed software for the various tests described above, and use this instrumentation to acquire data, control the tests and analyze the results. The availability of this equipment has also enabled us to reconfigure some existing equipment in order to provide a central data acquisition system for three creep machines, including the high temperature system purchase under this grant. Two of these creep machines and the central data acquisition system are being used in our AFOSR sponsored program on creep of high temperature aluminum alloys.

The Gatan ion mill and ancillary preparatory equipment will be used on a wide variety of research programs, including current and future work sponsored by AFOSR, NSF and DOE. Many of the materials that are of interest in our work contain a hard strengthening phase or undergo significant cavitation during deformation and failure. Ion milling will allow unambiguous identification of cavities and second phase particles and whiskers, since pitting or preferential removal of soft phases by electrolytic thinning of TEM specimens will be precluded. The size,

distribution and effects upon deformation and cavitation of extremely fine hard particles can be determined with TEM. The ancillary equipment permits specimens to be prepared for TEM more quickly than before. The dimpler reduces the amount of time needed for ion milling, prolonging the life of the ion mill. The ultrasonic cutter permits ceramic or composite materials to be cut into thin 3 mm discs. The punch permits metallic sheets to be cut easily into 3 mm discs with minimal deformation of the specimen. The grinder is designed to thin the discs to a thickness convenient for dimpling and milling. In general, this equipment will increase the quality and quantity of TEM foils that can be observed and analyzed.

The ATS high temperature vacuum creep machine is essential to our proposed AFOSR program on dispersion strengthened niobium alloys. The retort, vacuum system and furnace will be used initially to perform the diffusion of O and N into the Nb-1%Zr alloys for the formation of oxide and nitride particles, and to determine rate kinetics of the particle formation. Once specimens are made with the nitrides and oxides, creep experiments will be performed in vacuum. The high vacuum capabilities of this system are necessary in order to avoid oxidation of these alloys during testing, which would severly complicate the assessment of their creep resistance. This system will also be used to perform controlled atmosphere creep tests on the $Ni_3Al$ alloys as part of a NSF sponsored research program. In particular, the effect of hafnium additions in enhancing creep life in this alloy will be investigated. The vacuum system is essential for this work since this material exhibits dynamic embrittlement in the presence of oxygen at test temperatures.

In addition to the research programs described above, we anticipate that the instrumentation that we have purchased will lead to many other new experimental activities in the future. Some of the possible directions of this work were described in the grant proposal. We expect that our work will continue to focus on understanding the microstructure and mechanisms of deformation, creep, fatigue and fracture in structural materials, especially at elevated temperatures. The equipment provided under the present award is essential to our continued success in these activities.